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(54) TRACEABLE CABLE WITH SIDE-EMITTING OPTICAL FIBER AND METHOD OF FORMING THE SAME

(71) Applicant: **CORNING OPTICAL COMMUNICATIONS LLC**, Hickory, NC (US)

(72) Inventors: **Anthony Sebastian Bauco**, Horseheads, NY (US); **Douglas Llewellyn Butler**, Painted Post, NY (US); **Adam Kent Collier**, Montour Falls, NY (US); **Kevin Alton Lewis**, Montour Falls, NY (US); **Claudio Mazzali**, Painted Post, NY (US)

(73) Assignee: **Corning Optical Communications LLC**, Hickory, NC (US)

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G02B 6/028	(2006.01)
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CPC ***G02B 6/447*** (2013.01); ***C03B 37/025*** (2013.01); ***C03C 25/105*** (2013.01); ***G02B 6/028*** (2013.01); ***G02B 6/02052*** (2013.01); ***G02B 6/02395*** (2013.01); ***G02B 6/4479*** (2013.01); ***G02B 6/4486*** (2013.01); *C03C 2217/77* (2013.01); *C03C 2218/111* (2013.01); *C03C 2218/328* (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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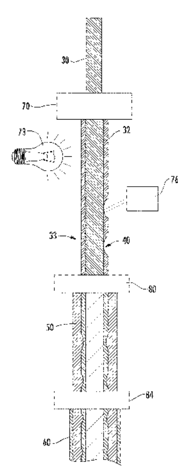
Primary Examiner — Hemang Sanghavi
(74) *Attorney, Agent, or Firm* — Robert L. Branham

(57) **ABSTRACT**

A traceable cable and method of forming the same. The cable includes at least one data transmission element, a jacket at least partially surrounding the at least one data transmission element, and a side-emitting optical fiber incorporated with and extending along at least a portion of the length of the cable. The side-emitting optical fiber has a core and a cladding substantially surrounding the core to define an exterior surface. The cladding has spaced apart scattering sites penetrating the exterior surface along the length of the optical fiber. The scattering sites scattering light so that the scattered light is emitted from the side-emitting optical fiber at discrete locations. When light is transmitted through the core, light scattered from the side-emitting optical fiber allows the cable to be traced along at least a portion of the length thereof.

20 Claims, 8 Drawing Sheets



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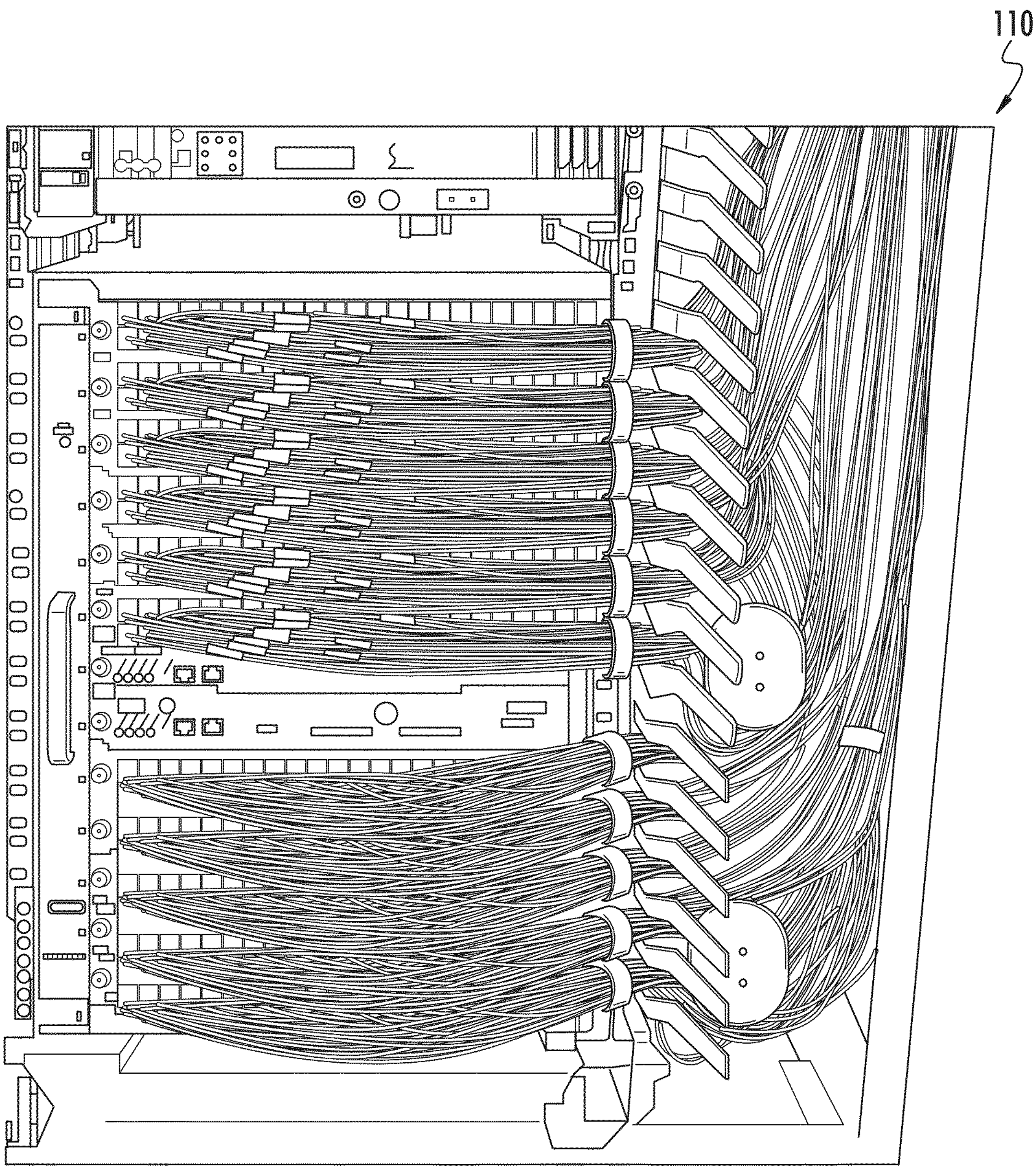

FIG. 1

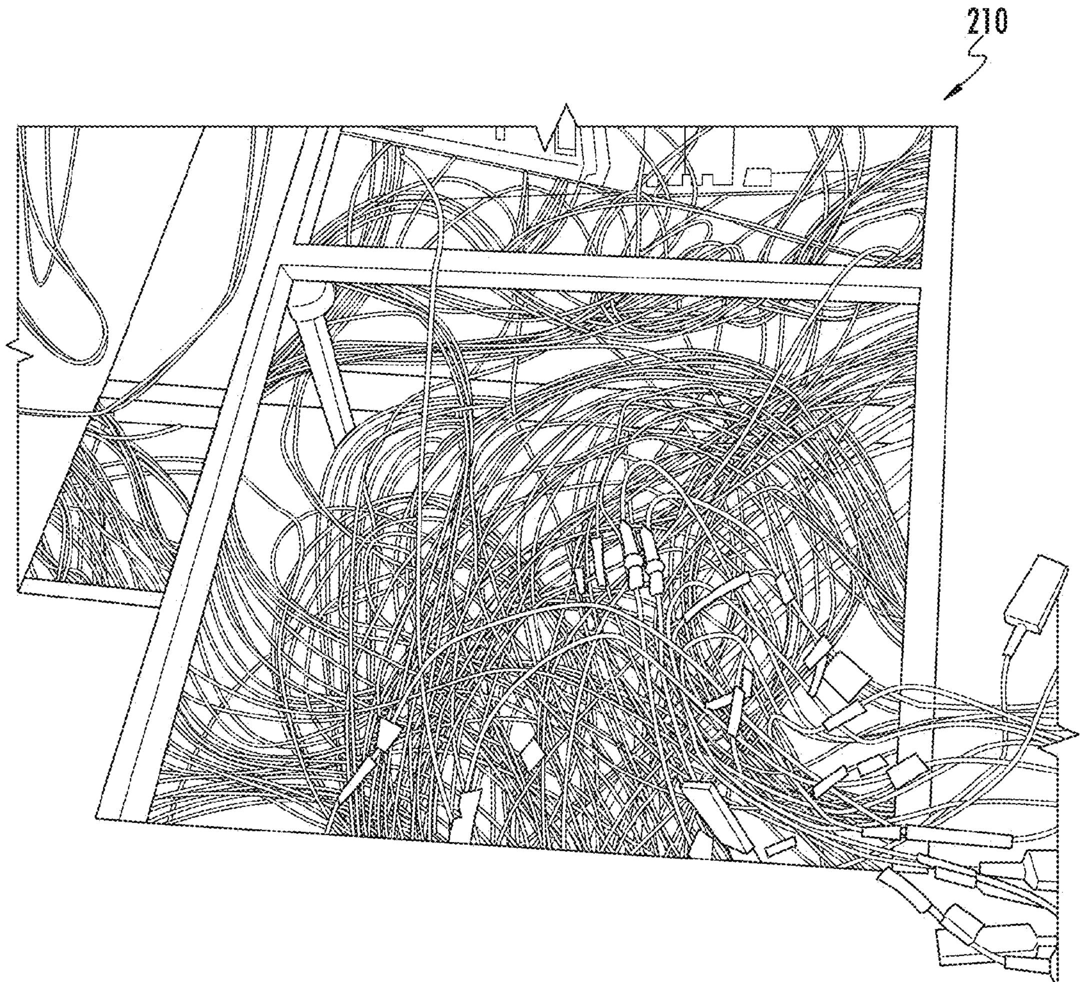

FIG. 2

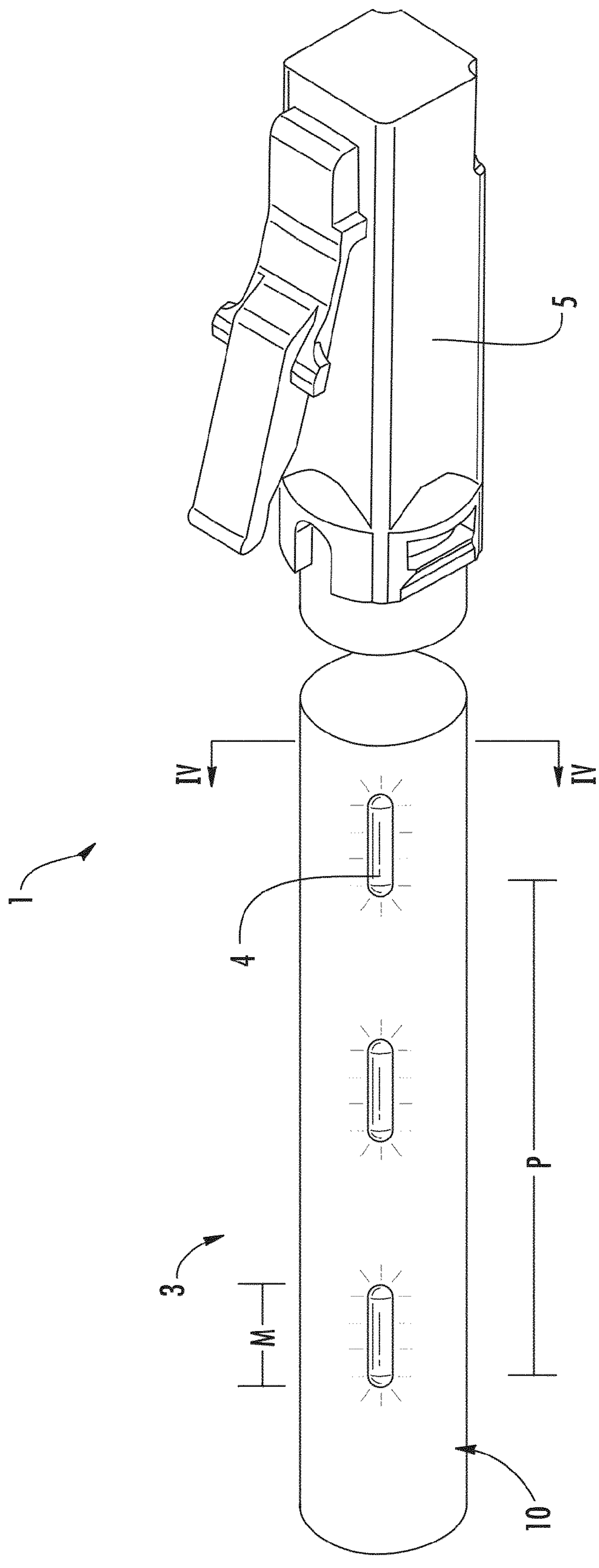

FIG. 3

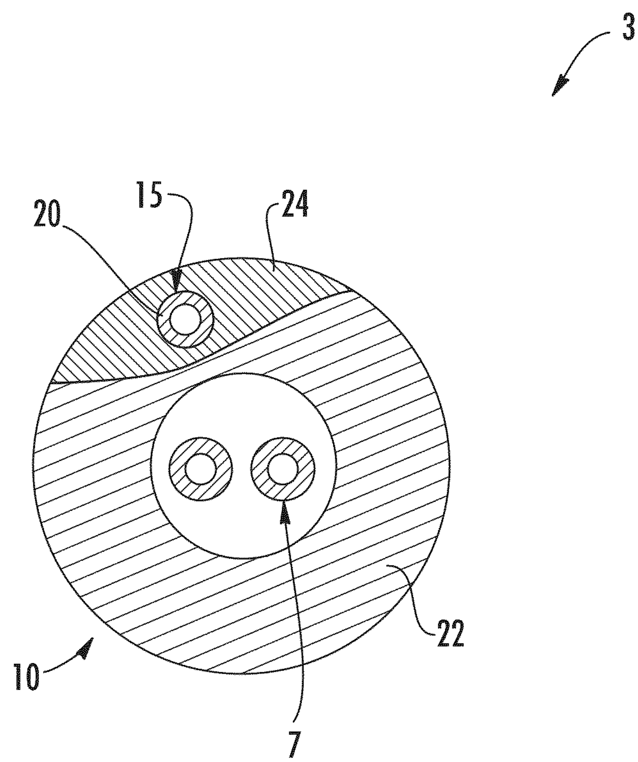

FIG. 4

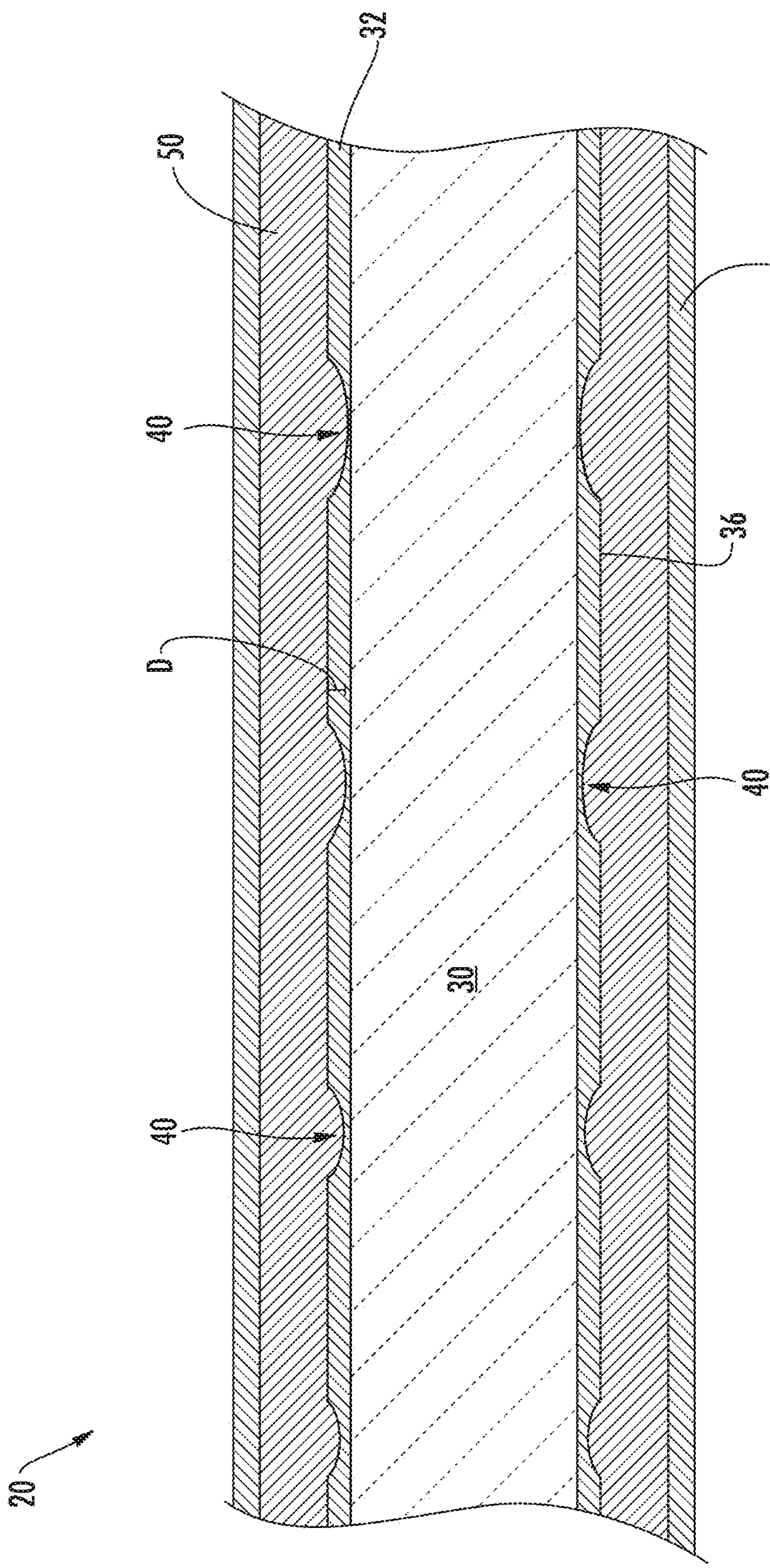

FIG. 5

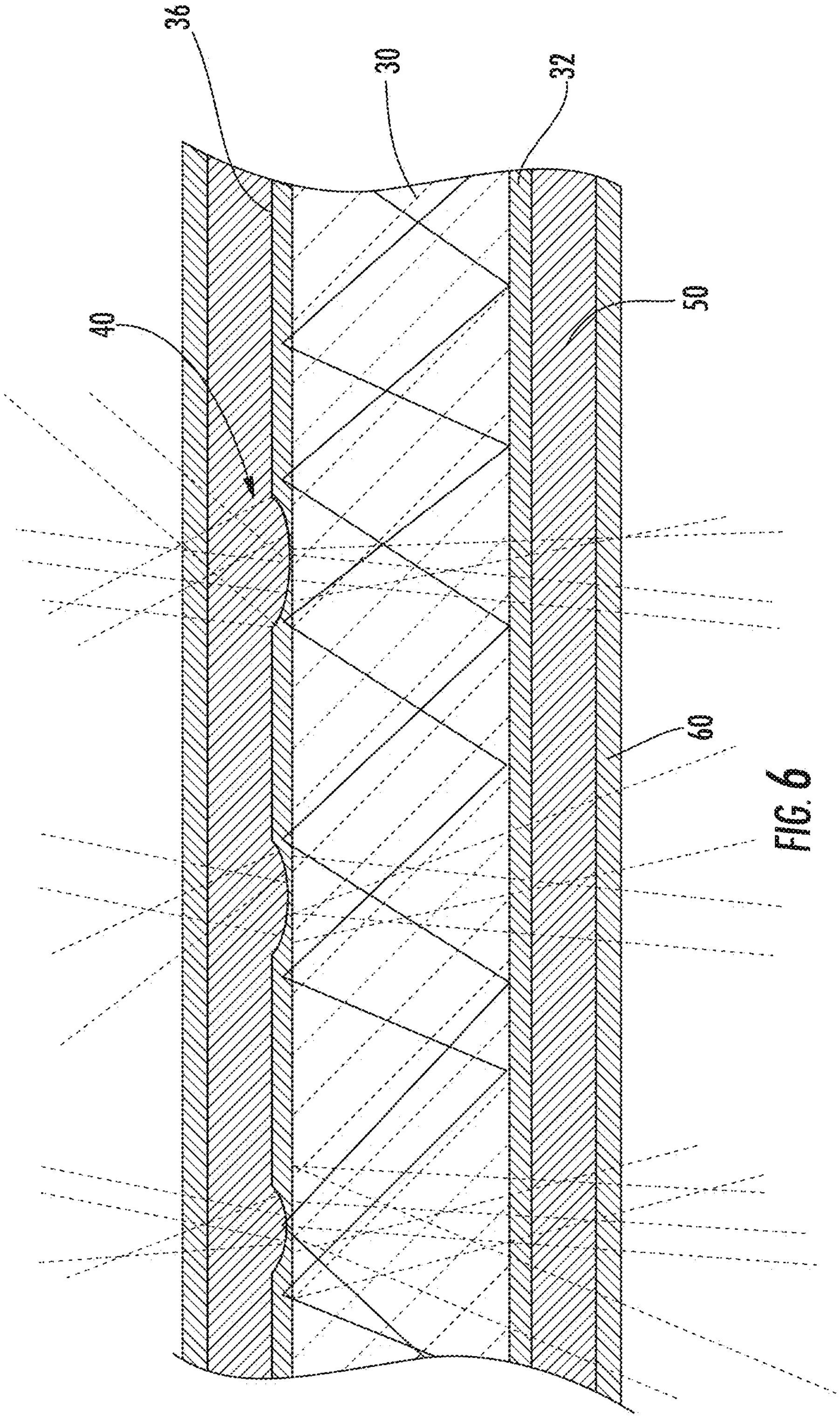

FIG. 6

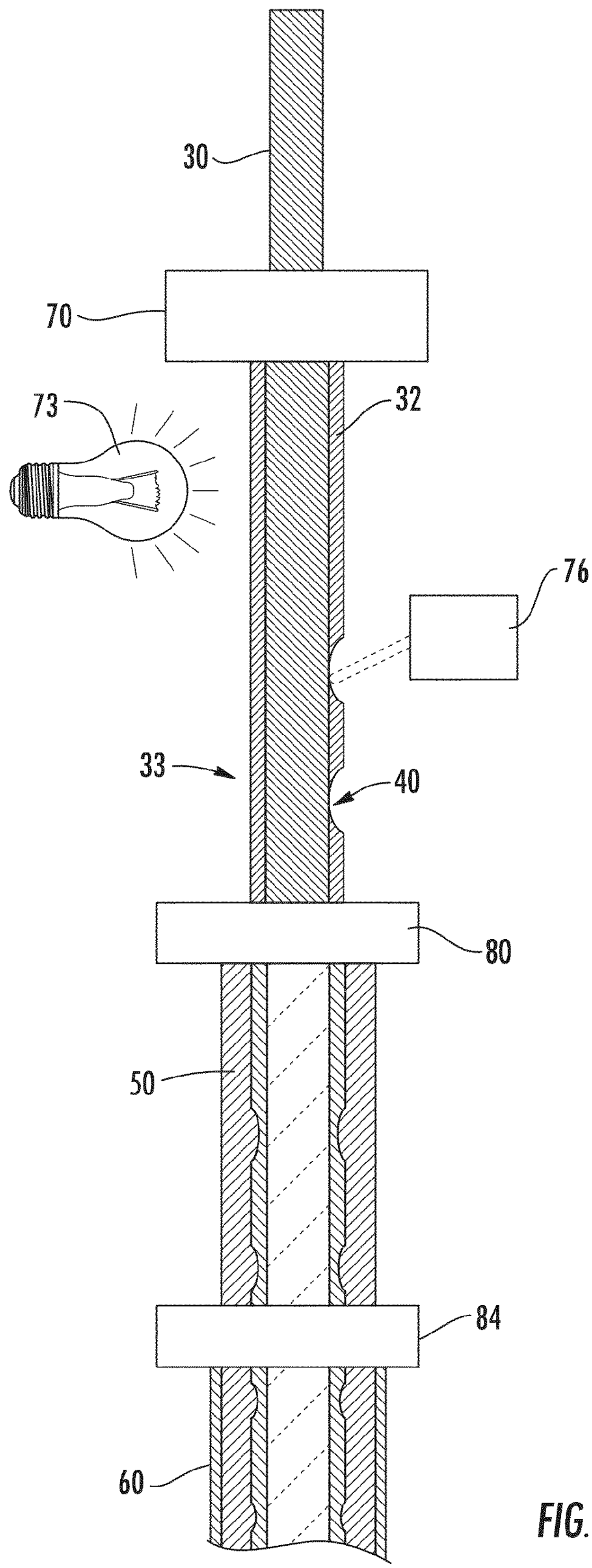

FIG. 7

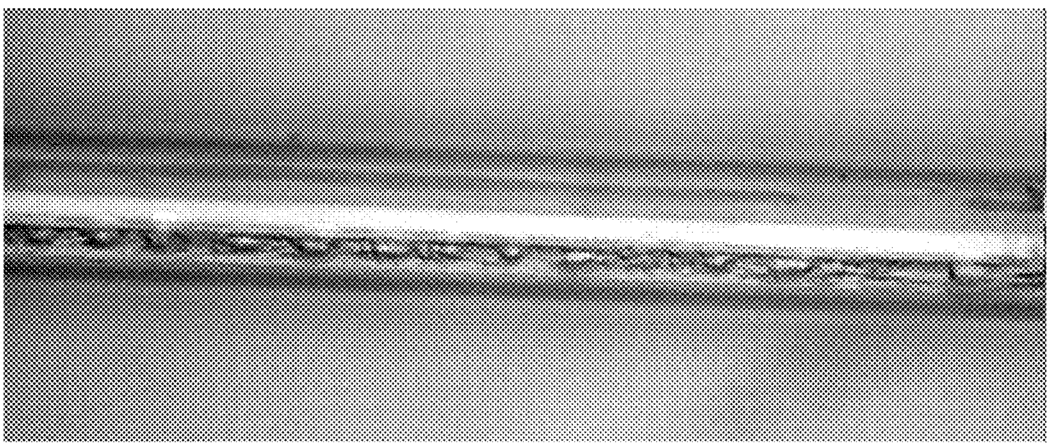

FIG. 8

TRACEABLE CABLE WITH SIDE-EMITTING OPTICAL FIBER AND METHOD OF FORMING THE SAME

PRIORITY APPLICATION

This application claims the benefit of priority under 35 U.S.C. §119 of U.S. Provisional Application Ser. No. 62/140,620, filed on Mar. 31, 2015, the content of which is relied upon and incorporated herein by reference in its entirety.

BACKGROUND

This disclosure generally relates to waveguides that scatter light from the side thereof. More particularly, this disclosure relates to cables and cable assemblies, such as patch cords, that are traceable due to the addition of a side-emitting optical fiber.

Today's computer networks continue to increase in size and complexity. Businesses and individuals rely on these networks to store, transmit, and receive critical data at high speeds. Even with the expansion of wireless technology, wired connections remain critical to the operation of computer networks, including enterprise data centers. Portions of these wired computer networks are regularly subject to removal, replacement, upgrade or other moves and changes. To ensure the continued proper operation of each network, the maze of cables connecting the individual components must be precisely understood and properly connected between specific ports.

In many cases, a network's cables, often called patch cords, can be required to bridge several meters across a data center. The cables may begin in one equipment rack, run through the floor or other conduit, and terminate at a component in a second equipment rack.

As a result, there is a need for a traceable cable that provides a means for the network operator to quickly identify the path and approximate terminal end of a given cable that is being replaced, relocated, or tested.

SUMMARY

The present disclosure includes traceable cables and side-emitting waveguides used in the same. In one embodiment of this disclosure, the cable includes at least one data transmission element, a jacket at least partially surrounding the at least one data transmission element, and a side-emitting optical fiber incorporated with and extending along at least a portion of the length of the cable. The side-emitting optical fiber has a core and a cladding substantially surrounding the core to define an exterior surface. The cladding has spaced apart scattering sites penetrating the exterior surface along the length of the optical fiber. The scattering sites scatter light so that the scattered light is emitted from the side-emitting optical fiber at discrete locations. When light is transmitted through the core, light scattered from the side-emitting optical fiber allows the cable to be traced along at least a portion of the length thereof.

The present disclosure also includes methods of forming traceable cables having at least one data transmission element and a jacket at least partially surrounding the at least one data transmission element. The method may comprise forming a side-emitting optical fiber by: adding a cladding around a glass core to create an exterior surface, the cladding having a lower index of refraction than the glass core, selectively ablating portions of the cladding to create scattering sites penetrating the exterior surface and configured to allow the side-emitting optical fiber to scatter light therefrom, and at least partially embedding the side-emitting optical fiber within the jacket so that the side-emitting optical fiber extends along at least a portion of a length of the cable.

The present disclosure also includes another method of forming a traceable cable that includes at least one data transmission element and a jacket at least partially surrounding the at least one data transmission element. The method may comprise forming an optical fiber by: passing a glass core through a first die block that applies a UV-curable cladding onto the glass core to form an optical fiber, wherein the cladding has a lower index of refraction than the glass core. The optical fiber is further formed by drawing the optical fiber past a laser, wherein the laser is pulsed as the optical fiber is drawn past the laser to selectively ablate portions of the cladding, the laser ablated portions defining scattering sites configured to allow the optical fiber to scatter light therefrom. Forming the optical fiber may further comprise passing the optical fiber through a second die block after selectively ablating portions of the cladding with the laser, wherein the second die block applies an acrylic coating over the cladding. The method may further include at least partially embedding the optical fiber within the jacket so that the optical fiber extends along at least a portion of a length of the cable.

Additional features and advantages will be set forth in the detailed description which follows, and in part will be readily apparent to those skilled in the art. It is to be understood that the foregoing general description, the following detailed description, and the accompanying drawings are merely exemplary and intended to provide an overview or framework to understand the nature and character of the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings are included to provide a further understanding, and are incorporated in and constitute a part of this specification. The drawings illustrate one or more embodiments, and together with the description serve to explain principles and operation of the various embodiments. Features and attributes associated with any of the embodiments shown or described may be applied to other embodiments shown, described, or appreciated based on this disclosure.

FIG. **1** is a perspective view of an equipment rack supporting patch cords.

FIG. **2** is a perspective view of an under-floor cable tray supporting patch cords.

FIG. **3** is a side view, partially in cross-section, of a portion of a traceable cable assembly according to one embodiment.

FIG. **4** is a cross-sectional view of the cable assembly of FIG. **3** along the plane IV-IV.

FIG. **5** is a lengthwise cross sectional view of a tracer element of the cable assembly according to embodiments of the present disclosure.

FIG. **6** is a schematic view of light propagating through and being scattered from the tracer element of FIG. **5**.

FIG. **7** shows a method of forming a side-emitting optical fiber as the tracer element of FIG. **5**.

FIG. **8** shows example scattering sites of the side-emitting optical fiber as viewed under a microscope.

DETAILED DESCRIPTION

Various embodiments will be further clarified by examples in the description below. In general, the description relates to side-emitting waveguides, cables, and cable assemblies using the waveguides to facilitate the traceability of the cable or cable assembly. This description also relates to methods of forming the side-emitting waveguides, cables and cable assemblies.

A problem that occurs in data centers or similar network locations is congestion and clutter caused by large quantities of cables. FIG. **1** shows an example of congestion in an equipment rack **110**. FIG. **2** shows congestion in an underfloor cable tray **210**. Network operators frequently desire to change connections to accommodate moves, adds, and changes in the network. However, such congestion makes it difficult to trace a particular cable from the source to the receiver, which may be required to perform the moves, adds, and changes in the network.

An aspect of this disclosure is the provision of side-emitting waveguides, usable within traceable cables, which provide efficient light emission that may provide visibility of the waveguide in well-lit rooms over a significant distance, wherein the waveguides may be produced by an efficient manufacturing method.

Turning back to the figures, FIG. **3** shows a cable assembly **1** with improved tracing capabilities according to embodiments of the present disclosure. The cable assembly **1** includes a cable **3**, tracer locations **4**, and a connector **5**. Although not shown, it should be understood that a connector **5** may be present on each opposite end of the cable **3** to allow the cable assembly **1** to act as a patch cord between components of a network. The connector **5** may vary widely depending on the nature of the cable **3** and the components being connected. The specific connector **5** selected should match the port configuration of the network component and will vary based upon the quantity and type of signals being transmitted by the cable **3**. The distance between the connectors **5** may define a length for the cable **3**. Cables **3** of the present disclosure are not specifically limited in their length, however, the cables **3** may have a length of at least about 1 meter and up to several tens of meters, such as one-hundred meters.

FIG. **4** shows a cross section of the cable **3** to represent one possible embodiment. The cable **3** may include one or more data transmission elements **7**. Two such data transmission elements **7** are shown. The data transmission elements **7** may be of the same type or different types as compared to one another. Generally, a data transmission element **7** is a structure capable of carrying a data signal from one end of the cable **3** to the other. The data transmission element **7** may be configured to transmit an electrical signal, for example, using a copper wire or other electrically conductive material. Alternatively, or in addition, the data transmission element **7** may be configured to transmit an optical signal by conducting electromagnetic waves such as ultraviolet, infrared, or visible light to carry data from one location to another.

In some embodiments, the cable **3** may be more appropriately referred to as a conduit, without having any data transmission elements **7**. Instead of transmitting a data signal, these cables **3** may transmit fluids such as air or liquid. These cables **3** may be appropriate for use in a medical setting such as IV lines or oxygen tubing. The cable **3** includes a jacket **10**. The jacket **10** may be a hollow tube forming a conduit that can substantially surround the data transmission elements **7** and that can define an outer surface of the cable **3**. Alternatively, the data transmission elements **7** may be at least partially embedded within the jacket **10**.

Cables **3** of the present disclosure include a tracer element **15**. The tracer element **15** is provided to enable the cable **3** to be selectively identified at one or more areas along the cable **3**. The tracer element **15** may be visually identified with or without special equipment, such as an IR camera.

One example of a tracer element **15** is a side-emitting optical fiber **20** used to identify one or more portions of the cable **3**. The side-emitting optical fiber **20** may be referred to interchangeably as a side-emitting optical waveguide herein. Therefore this disclosure does not intend to differentiate between the terms "optical fiber" and "optical waveguide" per se. The side-emitting optical fiber **20** may conduct nonvisible light. The side-emitting optical fiber **20** can also be used to conduct visible light, such as green light at approximately 532 nm. Red light, blue light, or a combination thereof could also be used to assist with tracing the cable **3**. Green light may be used due to the relative high degree of sensitivity of the human eye to green light.

As seen in FIG. **4**, the side-emitting optical fiber **20** is embedded within a portion of the jacket **10**. In alternative embodiments, the side-emitting optical fiber **20** could be adjacent to the data transmission elements **7** inside a cavity formed by the jacket **10**. If the side-emitting optical fiber **20** is within such a cavity, the jacket **10** may have at least some areas that are highly transparent. In yet other embodiments, the side-emitting optical fiber **20** could be provided on or mounted to the outside of the jacket **10**.

Still referring to FIG. **4**, the jacket **10** may include a pigmented portion **22** and an un-pigmented portion **24**. The pigment used in the pigmented portion **22** may be selected to identify the nature of the cable **3** to one of ordinary skill in the art, based on the number, type, and arrangement of data transmission elements **7** therein. The side-emitting optical fiber **20** may be embedded within the un-pigmented portion **24**. The un-pigmented portion **24** may include some pigment, but is typically more optically transparent than the pigmented portion **22**. Therefore by locating the side-emitting optical fiber **20** within the un-pigmented portion **24**, any light scattered from the side-emitting optical fiber **20** will be more visible.

Turning to FIG. **5**, the side-emitting optical fiber **20** includes at least a core **30** and a cladding **32**. The core **30** may be made from glass, particularly silica-based glass, having a first index of refraction. Alternatively, the core **30** may be formed from a polymer. The size of the core **30** is not particularly limited, but in some embodiments diameters may be between and including about 100 microns and about 250 microns. The core may be, for example, 125 microns. Cores that are significantly smaller may be subject to damage from handling, and cores that are significantly larger may be subject to damage when bending.

In some embodiments, the core **30** may be a substantially solid core, generally free of voids or air pockets as found within the airline optical fiber type of diffusive optical fibers. A core **30** that is free from voids may facilitate splicing, polishing, or other processing operations, which may be needed in some embodiments to make ends of the side-emitting optical fiber **20** compatible with a device for launching light into the side-emitting optical fiber.

The cladding **32** can be a polymer, such as fluoro-acrylate. In the embodiment illustrated in the drawings, the material for the cladding **32** is selected to have an index of refraction that differs from the index of refraction of the core **30**. In some embodiments the index of refraction of the cladding **32** is lower than that of the core. In some embodiments, the indices of refraction produce a step-index optical fiber. In other embodiments, the side-emitting optical fiber **20** may be a trapezium or triangular index fiber. The cladding **32** closely surrounds the core **30** to help maintain light within the side-emitting optical fiber **20**. The cladding **32** may have a thickness between about 4% and about 40% of the diameter of the core. For example, the cladding **32** may be between about 5 and about 50 microns thick from the surface of the core **30** to an exterior surface **36** of the cladding **32** when the core **30** has a diameter of 125 microns.

According to embodiments of the present description, scattering sites **40** are selectively provided at spaced apart locations on the cladding **32** along the length of the side-emitting optical fiber **20**. The scattering sites **40** are configured to provide areas where light, which is otherwise traveling along the side-emitting optical fiber **20**, is scattered and therefore able to be emitted from the side of the side-emitting optical fiber **20**, as shown in stippled lines in FIG. **6**, to form the tracer locations **4** shown in FIG. **3**.

The scattering sites **40** are areas where the exterior surface **36** is modified, removed, deformed, or damaged to produce optical surfaces tending to scatter incoming light. Some or all of the scattering sites **40** may be annular or otherwise generally ring shaped, extending around the entire circumference of the side-emitting optical fiber **20**. In some embodiments, as understood from FIG. **6**, each scattering site **40** does not extend around the full circumference of the side-emitting optical fiber **20**. The scattering sites **40** may sweep an arc approximately 180 degrees, 90 degrees, or even less around the circumference.

A complete ring shape may provide the most uniformly scattered light, but a full ring is not believed necessary to have light scatter in all 360 degrees around a lengthwise axis of the side-emitting optical fiber **20** and/or light to be seen 360 degrees a lengthwise axis of the cable **3**. The scattering sites **40** scatter light generally in all directions with varying intensity. Therefore, each scattering site **40** directs light immediately out of an adjacent portion of the exterior surface **36**, and also directs light back through the core **30** and out an opposite portion of the exterior surface **36** as schematically illustrated in FIG. **6**. Scattering light from the side-emitting optical fiber **20** about 360 degrees can be desired to avoid directionality in the side-emitting optical fiber **20**. Directionality may require more precise orientation of the side-emitting optical fiber **20** with the jacket **10** and cable **3**. If the side-emitting optical fiber **20** emitted light in to a particular direction, that emission direction may need to be oriented toward the exterior of the cable **3** to be visible. Again, by scattering light 360 degrees around the side-emitting optical fiber **20**, the side-emitting optical fiber allows the scattered light be to be seen from any viewpoint around the lengthwise axis of the cable **3**.

The scattering sites **40** may be produced by a variety of mechanical, optical, or chemical processes. In the embodiment of FIG. **7**, the scattering sites **40** are produced as the result of ablation caused by impact with high intensity light from a laser **76**. The ablation process removes some of the cladding **32** and leaves behind an optically rough surface portion.

Several characteristics of the scattering sites **40** may be refined to help ensure that the extraction of light from the core **30** and cladding **32** to provide tracer locations **4** along the cable **3** are each visible in a well-lit environment. The characteristics may also be refined based the practical manufacturability of the cable **3** and side-emitting optical fiber **20**.

First, the separation P between the scattering sites **40** may be selected to address the unique challenges associated with cable assemblies for data centers or similar network locations. In one embodiment, the scattering sites **40** should be at least about 1 cm apart and less than about 1 meter apart. Scattering sites **40** that are too close together approach a uniform emission along the length of the cable **3**, and may lose the efficient use of light provided by the discrete tracer locations **4**. Scattering sites **40** that are too far apart may lose the benefits of along-the-length tracer locations **4** and the ability to sufficiently trace the cable **3** in its environment with other cables. Additionally, scattering sites **40** that are too far apart may result in no scattering sites **40** sufficiently close to the terminal end of the cable **3** to provide a tracer location **4** within the appropriate equipment rack **110**. An approximate separation P of about 10 cm may balance the light efficiency and traceability benefits, keeping in mind that several of the tracer locations **4** may be hidden behind other cables, effectively increasing the relative spacing between each tracer location **4**. In some embodiments, the separation P may facilitate identifying the overall length of the cable **3**. For example, the approximate separation P may be about 1 meter in some embodiments, thereby allowing a person to count the tracer locations **4** to approximate the total length of the cable **3** in meters. In other embodiments, the approximate separation P may be about 1 foot, thereby allowing a person to count the tracer locations **4** to estimate the total length of the cable **3** in feet.

As used herein, the cable **3** and the side-emitting optical fiber **20** may be described as each having respective launched ends and traced ends. The launched ends can be the known, accessible end of the cable **3** and end of the side-emitting optical fiber **20** where the network operator would provide (i.e. launch) tracer light to the side-emitting optical fiber **20**. The respective traced ends should therefore be understood as the respective ends of the cable **3** and optical fiber **20** opposite the launched ends. The traced end, particularly of the cable **3**, is the end of the cable that needs to be identified by the tracing process. It should be understood that these ends are not fixed. For any given operation, either end of the cable **3** may constitute the launched end and the traced end.

The size of each scattering site **40** may also be based on the challenges associated with cable assemblies for data centers or similar network locations. The size of each scattering site **40** may include the arc sweep around the side-emitting optical fiber **20**. The size of each scattering site **40** may also include the magnitude M (FIG. **3**) along the length of the side-emitting optical fiber **20** (i.e., "magnitude M" refers to the length of each scattering site measured parallel to the lengthwise axis of the side-emitting optical fiber **20**). In some embodiments, the magnitude M may be between about 10 microns and about 50 mm, or even between about 0.5 mm and about 4 mm (such as about 2 mm for one specific example).

Further, the scattering sites **40** may be characterized by their depth D (FIG. **5**) from the exterior surface **36** to a point closest to the core **30**. One skilled in the art will appreciate that light traveling through the side-emitting optical fiber **20** may be described as forming a bell shaped distribution pattern relative to the central lengthwise axis of the core **30**. The edges of the distribution, the part traveling through the cladding **32**, may be referred to as the evanescent tail of the propagating light. It is this tail that is clipped by the scattering sites **40** and sent traveling in all directions. Therefore, the deeper each scattering site **40** penetrates into the cladding **32**, the greater portion of the light distribution that is available for scattering by the scattering site **40**. Therefore, selecting the depth D of each scattering site **40** balances the desire to scatter out a sufficient amount of light to be visible in a well-lit room with the desire to maintain enough light within the side-emitting optical fiber **20** to provide sufficient light to each of the scattering sites **40** downstream.

In an extreme example, the scattering sites **40** may remove the cladding **32** completely down to the core **30**. In one example, the scattering sites **40** do not completely remove the cladding **32** at the given location. Depths D may include between about 1% to about 100% of the thickness of the cladding **32**. Yet again, the depth D of each scattering site **40** may be substantially consistent along the length of the cable **3**. Alternatively, the depth D may vary as a function of the distance from an end of the cable **3** or side-emitting optical fiber **20**. For example the depth D may increase with distance from the launched end. The depth D is generally defined as a maximum distance toward the core **30** or a maximum percentage of cladding removal for any given scattering site **40**. The process used, and resulting surface profile of each scattering site **40**, is likely to render a range of depths for any given scattering site **40**. In some embodiments, the range of depths may be minimized and essentially random. In other embodiments, the range of depths may be provided with a general profile, like the concave areas represented in FIGS. **5** and **6**.

The side-emitting optical fiber **20** may include at least one coating **50** applied to the exterior surface **36** and scattering sites **40** of the cladding **32**. The coating **50** may be between about 10 and about 70 microns thick. The coating **50** may be provided as a layer of protection for the core **30** and the cladding **32**. The coating **50** should be at least translucent, if not fully transparent, in locations corresponding with the scattering sites **40**. The coating **50** may have light transmission windows or have generally uniform light transmission characteristics. The coating **50** may be made from acrylate. The refractive index of the coating **50** may be 1.56 relative to the refractive index of the optical cladding **32** of 1.35.

The side-emitting optical fiber **20** may also include an ink layer **60** applied to the coating **50**. The ink layer **60** may be selectively applied to locations corresponding with the scattering sites **40**. Alternatively, the ink layer **60** may be uniformly applied to the coating **50**. The ink layer **60** may have further scattering elements, such as titanium oxide spheres, configured to diffuse the light being emitted from the side-emitting optical fiber **20**. The ink layer **60** is configured to provide each tracer location **4** with an approximate Lambertian distribution pattern.

The side-emitting optical fiber **20** of the present disclosure has been described for use in facilitating traceability of a cable **3**. In some embodiments, the side-emitting optical fiber **20** may have uses independent of the cable **3**. For example, the side-emitting optical fiber **20** may not be used for tracing at all, but may itself provide decorative or functional illumination or indication.

Side-emitting optical fibers **20** according to this disclosure may be manufactured according to a process schematically illustrated in FIG. **7**. A core **30**, such as a glass core may be fed, pulled, or drawn, or otherwise passed at typical telecom speeds through a first liquid die block **70**. There, a cladding **32** is deposited or otherwise applied to the core **30**. In one example, process for adding the cladding **32** may be a pultrusion process. The cladded core **33** may pass through a curing station **73** where the cladding **32** is at least partially cured. In one example, the curing station **73** may emit UV light from lamps or LEDs to rapidly, optically cure the cladding **32**.

After the cladding **32** is at least partially cured, the scattering sites **40** may be created by ablating the exterior surface **36** with at least one high intensity light source, such as a laser **76** as the cladded core **33** is drawn past. Two or more light sources positioned around the core **30** may be provided to achieve the desired arc sweep for each scattering site **40**. The high intensity light impacts the cladding **32** and forms the scattering sites **40** by vaporizing or burning off some of the cladding **32** while locally affecting other portions of the cladding **32** to produce the resulting locally roughened surface as shown in FIG. **8**. The roughened surface may be described as having a series of defects or voids. It should be recognized that the scattering sites **40** will be at least as large as the wavelength of the laser **76**. Using a less collimated beam emitted from slightly further from the cladded core **33** can produce scattering sites **40** that are wider radially. The laser **76** is also likely to cause a hot spot on the cladding **32** that spreads beyond the area directly in path with the light beam.

In one embodiment, each laser **76** is a CO2 laser, running at a repetition rate of 0.25 Hz to 100000 Hz with pulse energies of approximately 10000 W/s to 20000 W/s and pulse duration of 0.1 μs to 10 seconds. As will be appreciated by one of ordinary skill in the art, other types of lasers, emitting other wavelengths of light, may be used. The repetition rate, pulse energy, and pulse duration may all be adjusted based on the draw rate of the cladded core **33** to achieve scattering sites **40** with the desired separation P, magnitude M, and depth D.

After the formation of the scattering sites **40** penetrating the exterior surface **36** of the cladding **32**, the cladded core **33** may pass through a second liquid die block **80** where a similar pultrusion process may add a coating **50** over the ablated cladding. The coating **50** may be cured as it passing through a second curing station (not shown), or may be cured by other known means, such as temperature.

To provide a smoother, more Lambertian, light distribution pattern from the side-emitting optical fiber **20**, a scattering ink layer **60** may be applied onto the coating **50** at a third liquid die block **84**, or other processing unit, such as a spray applicator or printer.

In one embodiment, the side-emitting optical fiber **20** is manufactured on a single draw. As will be understood by those of skill in the art, the side-emitting optical fiber **20** can be produced in a continuous fashion on a single line, at a single location. Alternatively, it is possible that the side-emitting optical fibers **20** of the present description could also be produced by discrete steps at separate locations. For example, the core **30** may be wound up, transported between locations or manufacturing stations, and then run through the first liquid die block **70** for cladding. In another example, the scattering sites **40** may be created separate from the drawing of the cladded cores **33**.

The side-emitting optical fibers **20** may continue on the single line directly to the manufacture of the cable **3**. Alternatively, the side-emitting optical fiber **20** may be separately combined with the data transmission elements **7** and the jacket **10** in a different location or distinct time. In one embodiment, an extrusion or pultrusion process may be used to at least partially embed the side-emitting optical fiber **20** with the jacket **10** as the jacket **10** is being formed around the data transmission element **7**. The side-emitting optical fiber **20** may be combined with at least one data transmission element **7** and a jacket **10** by a variety of processes known in the art, depending upon the particular type of cable **3** that is being manufactured.

Cable assemblies **1** may be made by cutting the cable **3** to a desired length and attaching the desired connectors **5** to each end according to processes known in the art, and dependent upon the type of cable assembly **1** being produced. For example, the connector **5** may be SC, LC, ST, FC, or MPO type connectors.

The side-emitting optical fibers **20**, cables **3** that incorporate the side-emitting optical fibers **20**, and cable assemblies **1** that incorporate the cables **3**, each have several advantages that will be apparent to one of ordinary skill in the art. Particularly, use of a side-emitting optical fiber **20** within the cable **3** provides an improved ability for a network operator to quickly and efficiently trace a particular cable assembly **1** so that a traced end can be identified from a predetermined launched end of the cable assembly **1**. The side-emitting optical fibers **20** of this disclosure can be configured to facilitate the ability to trace along the full length of the cable **3**. This may be helpful to identify tangles or knots. This may also help when the particular equipment rack **110**, in which the traced end is connected, is unknown. For example, equipment racks **110** often have front doors that are kept closed. Tracing along the length of the cable **3** may help identify which rack to search. If a tracer location **4** were only on the traced end the cable **3**, it may be hidden behind the door.

While side-emitting optical fibers **20** according to this disclosure may provide tracer locations **4** along the length of a cable **3**, they are usually not intended to provide continuous illumination along the length. As a result, the side-emitting optical fibers **20** are able to make more efficient use of a tracer source light. This means that tracer locations **4** can be provided along cables **3** of significant length, for example 30m or more, while the tracer locations **4** may remain sufficiently bright to be readily visible in a well-lit room using a tracer source light of reasonable intensity.

A tracer light source may be integrated into the cable **3**, or the connector **5**, to illuminate the side-emitting optical fiber **20**. In some embodiments, however, a separate tracer light source may be used to selectively emit light into the side-emitting optical fiber **20**. By using a separate tracer light source, the cost of the cable **3** may be reduced compared to systems integrating a light source or using active light sources along the length to form the individual tracer locations **4**.

In advantageous embodiments, the side-emitting optical fiber **20** can be made with a continuous manufacturing process where each step is performed on a single draw. Such a continuous process may provide a high rate of manufacture with minimum waste, transportation costs or labor costs. Use of laser ablation to form the scattering sites **40** provides a processing step that can be readily controlled in terms of pulse rate, pulse energy, and duration to finely tune the separation, arc sweep, and magnitude of the scattering sites **40** to achieve the best combination of traceability, brightness, and manufacturing efficiency.

Persons skilled in waveguide technology will appreciate additional variations and modifications of the devices and methods already described. Additionally, where a method claim below does not explicitly recite a step mentioned in the description above, it should not be assumed that the step is required by the claim. Furthermore, where a method claim below does not actually recite an order to be followed by its steps or an order is otherwise not required based on the claim language, it is not intended that any particular order be inferred.

The above examples are in no way intended to limit the scope of the present invention. It will be understood by those skilled in the art that while the present disclosure has been discussed above with reference to examples of embodiments, various additions, modifications and changes can be made thereto without departing from the spirit and scope of the invention as set forth in the claims.

What is claimed is:

1. A traceable cable formed by:
- forming an optical fiber, wherein the optical fiber is formed by:
  - passing a glass core through a first die block that applies a UV-curable cladding onto the glass core to form an optical fiber, wherein the cladding has a lower index of refraction than the glass core;
  - drawing the optical fiber past a laser, wherein the laser is pulsed as the optical fiber is drawn past the laser to selectively ablate portions of the cladding, the laser ablated portions defining scattering sites configured to allow the optical fiber to scatter light therefrom; and
  - passing the optical fiber through a second die block after selectively ablating portions of the cladding with the laser, wherein the second die block applies an acrylic coating over the cladding; and
- at least partially embedding the optical fiber within a jacket so that the optical fiber extends along at least a portion of a length of the jacket, wherein the jacket defines an exterior surface of the traceable cable.

2. The traceable cable of claim **1**, wherein the cladding comprises fluoro-acrylate.

3. The traceable cable of claim **1**, wherein the scattering sites extend completely through the cladding.

4. The traceable cable of claim **1**, wherein the scattering sites do not extend to the core.

5. The traceable cable of claim **1**, wherein the scattering sites are configured to scatter light in all directions around a lengthwise axis of the optical fiber.

6. The traceable cable of claim **1**, wherein at least some of the scattering sites extend fully around a circumference of the optical fiber.

7. The traceable cable of claim **1**, wherein at least some of the scattering sites extend only partially around a circumference of the optical fiber.

8. The traceable cable of claim **1**, wherein the scattering sites are periodically spaced along the length between about 4 cm and about 1 m apart.

9. The traceable cable of claim **1**, wherein the optical fiber is a step-index optical fiber.

10. The traceable cable of claim **1**, wherein each scattering site has a magnitude between about 0.1 mm and about 50 mm along a length of the optical fiber.

11. The traceable cable of claim **10**, wherein the magnitude varies as a function of the distance from an end of the optical fiber.

12. The traceable cable of claim **1**, wherein the jacket comprises a pigmented portion and an un-pigmented portion, the optical fiber being at least partially embedded in the un-pigmented portion.

13. The traceable cable of claim **1**, wherein to core of the optical fiber has a diameter between about 100 microns and about 250 microns, the cladding has a thickness between about 4% and about 40% of the diameter of the core, and the optical fiber is a step-index optical fiber.

14. The traceable cable of claim **1**, wherein depth of the scattering sites varies as a function of the distance from an end of the optical fiber or the traceable cable.

15. The traceable cable of claim **1**, wherein the jacket at least partially surrounds at least one data transmission element of the traceable cable.

16. The traceable cable of claim **15**, wherein the at least one data transmission element is an optical fiber.

17. A method of forming a traceable cable that includes at least one data transmission element and a jacket at least partially surrounding the at least one data transmission element, the method comprising:
- forming an optical fiber by:
  - passing a glass core through a first die block that applies a UV-curable cladding onto the glass core to form an optical fiber, wherein the cladding has a lower index of refraction than the glass core;
  - drawing the optical fiber past a laser, wherein the laser is pulsed as the optical fiber is drawn past the laser to selectively ablate portions of the cladding, the laser ablated portions defining scattering sites configured to allow the optical fiber to scatter light therefrom; and
  - passing the optical fiber through a second die block after selectively ablating portions of the cladding with the

laser, wherein the second die block applies an acrylic coating over the cladding; and

at least partially embedding the optical fiber within the jacket so that the optical fiber extends along at least a portion of a length of the cable.

18. The method of claim **17**, wherein the laser that is pulsed is a 10.6 micron CO2 laser, running at a repetition rate of 2-100 Hz with laser energy of 10000 W/sec on a fiber moving 5 m/s and pulse duration of 0.8 ms (micro seconds).

19. The method of claim **17**, further comprising applying an ink layer to the acrylic coating.

20. The method of claim **17**, wherein drawing the optical fiber past a laser comprises forming the scattering sites at locations spaced apart by single unit of length in the International System of Units or Imperial System, and further wherein the optical fiber is at least partially embedded in the jacket such that the scattering sites can be counted to approximate an overall length of the cable.

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